# ONR Graduate Traineeship Award Update

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Award Number: N00014-07-0223
http://mpl.ucsd.edu

## LONG-TERM GOALS

This project's goal is to explore ways of using ambient noise in the ocean to extract the physical characteristics of the ocean environment. In addition, this research is the the PI's Ph.D. research, leading to her completed Ph.D. this term.

## OBJECTIVES

Noise correlation processing extracts coherent signals from seemingly random noise data. Although this technique has been successfully used in processing ocean ambient noise data it has severe limitations due to the changing ocean environment and the spatial and temporal variability of the ambient noise field. In this project we are: (1) investigating the physics of the noise processing procedure that constrains the optimum correlation, (2) attempting to understand where and how the degradation of the derived time domain Green's function (TDGF) comes about, and (3) exploit array and signal processing techniques to optimize the signal-to-clutter (otherwise known as the 'signal-to-noise') rate of the noise correlation processing.

## APPROACH

This work uses primarily real ocean data, with some comparison with simulations and the developing theory of ambient noise correlation. Two data sets have been used: one is from the Adaptive Beach Monitoring (ABM) experiment in 1995, the other from the Noise10 Experiment in 2010. The data recorded by the ABM sensors, the ambient noise recorded on each pair of sensors was cross-correlated to find the time-of-arrival information between sensors. Using the data from the Noise10 Experiment the recordings were combined into beams (using planewave beamforming) for varying array shapes and sizes and then correlated. The signal-to-noise ratio (SNR) of the resulting correlated signals are compared with reference to the physics of the array and of the measured noise field.

This work was greatly aided by my advisor, Professor William Kuperman, research scientist Shane Walker, and Prof. Karim Sabra (formerly of MPL, now at Georgia Tech). Prof. Sabra had previously laid much of the groundwork for this research and allowed me to build upon his suite of noise processing models.

# Report Documentation Page

*Form Approved*
*OMB No. 0704-0188*



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|---|---|---|
| 1. REPORT DATE<br>**SEP 2011** | 2. REPORT TYPE | 3. DATES COVERED<br>**00-00-2011 to 00-00-2011** |

| | |
|---|---|
| 4. TITLE AND SUBTITLE<br>**ONR Graduate Traineeship Award Update** | 5a. CONTRACT NUMBER<br>5b. GRANT NUMBER<br>5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | 5d. PROJECT NUMBER<br>5e. TASK NUMBER<br>5f. WORK UNIT NUMBER |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>**University of California, San Diego,Marine Physical Laboratory, Scripps Institution of Oceanography,9500 Gilman Drive,La Jolla,CA,92093-0238** | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSOR/MONITOR'S ACRONYM(S)<br>11. SPONSOR/MONITOR'S REPORT NUMBER(S) |

12. DISTRIBUTION/AVAILABILITY STATEMENT
**Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT<br>**unclassified** | b. ABSTRACT<br>**unclassified** | c. THIS PAGE<br>**unclassified** | **Same as Report (SAR)** | **6** | |

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Prescribed by ANSI Std Z39-18

## WORK COMPLETED

This project will be completed within the semester, culminating in a Ph.D. for the P.I. Varying shaped arrays have been used to incorporate beamforming into the noise correlation function. The resliationship between the beampattern produced by the array and the resulting correlation function has been explored. In addition, measurements of the noise field align with SNR calculations for the noise correlation.

## RESULTS

This last year has been the cumination of this work, and produced significant results on this project. What follows is a brief overview.

Incorporating beamforming into the noise correlation function dramatically reduces the time needed to build up the correlation. Figures 1 and 2 compare the noise correlation of individual sensors on each of the Noise10 Experiment's arrays over 4 days of the experiment with the correlation results using the beams of all the sensors. The arrays were 323.7m apart, so the expected arrival time is approximately 0.22 seconds. On each plot the vertical axis shows the minute index for the experiment. The horizontal axes on the color plots are the correlation time, centered around the positive and negative expected arrival times. The color axis is in normalized dB. The right hand plot in each case shows the measured SNR for each line of the color plots – blue x's for positive arrival time, green x's for negative arrival time. Each line of the correlation in Fig. 1 is a 60 minute average of the single sensor correlations. Each line of Fig. 2 is a 15 minute average of the arrays.

We can predict that given any array geometry the improvement in the SNR with the size of the array should linear given an isotropic noise field. However, as we do not have that in the ocean we can predict the most effective shape for an array (for instance if we are limited to line arrays there is the question of placing them in line with each other or parallel to each other) by analyzing the beampattern produced by those arrays within the context of the measured (or if not-measurable, assumed) noise field.

Given the definition used for SNR of ambient noise cross-correlations we predict the effect of increased time averaged in the correlations on the measured SNR to be an improvement of up to square root of the time correlated. This improvement is limited by variation in the environment. Figure 3 shows the mean SNR measured for correlations of increasing time for three possible array setups – using the full `L' shaped arrays, using only the line arrays which, when beamed, create broadside beams when pointed in the same direction, and using only the line arrays which, when beamed, created endfired beams when pointed in the same direction. From the analysis of the beampatterns of these different array shapes we predict that the 'L' shaped array should work best, and the 'endfire' arrays worst.

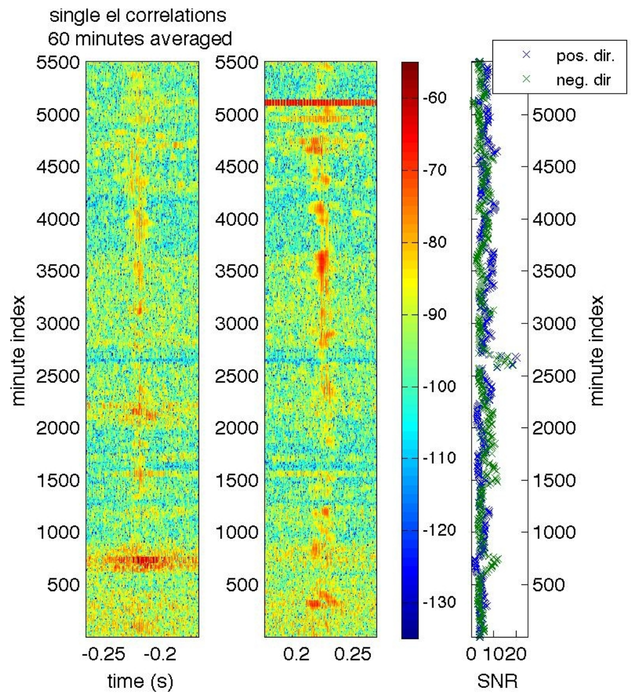


***Figure 1: Cross correlation of a single sensor from each array and the SNR measured for 60 minute long correlations throughout the 4 days of data. Left hand and center plots show the correlation signal for positive (center plot) and negative (left plot) time lag. The sensors were 323.7 m apart, so the expected arrival time should be approximately 0.22 seconds. The vertical axis shows the minute index of the experiment, and the horizontal axis shows the correlation time centered around the positive and negative expected arrival time. The color bar is in normalized dB. The right hand plot shows a measure of the SNR for each line of the plots to the left: blue x's show the SNR measured for the positive arrival time, green x's show the measured SNR for the negative arrival time.***

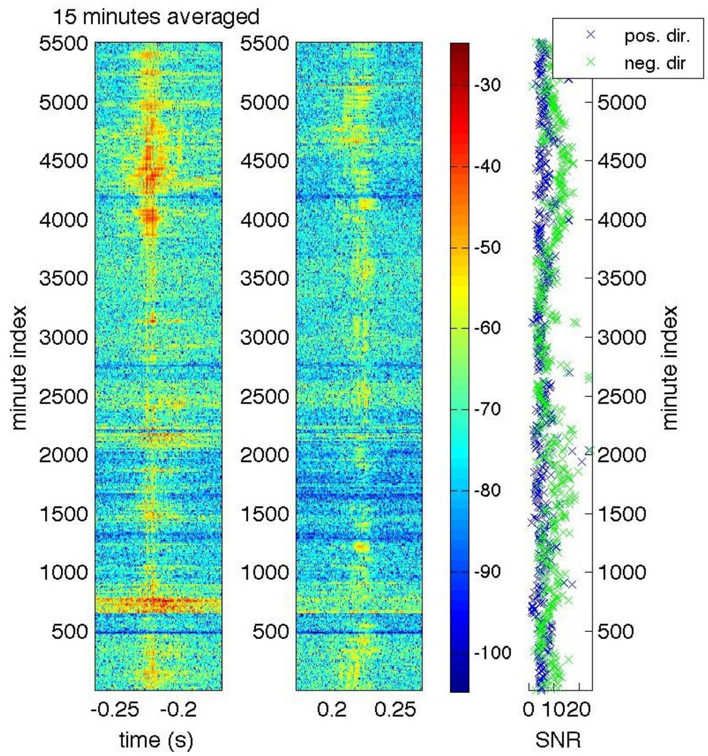


***Figure 2: Cross correlation of a single sensor from each array and the SNR measured for 60 minute long correlations throughout the 4 days of data. Left hand and center plots show the correlation signal for positive (center plot) and negative (left plot) time lag. The sensors were 323.7 m apart, so the expected arrival time should be approximately 0.22 seconds. The vertical axis shows the minute index of the experiment, and the horizontal axis shows the correlation time centered around the positive and negative expected arrival time. The color bar is in normalized dB. The right hand plot shows a measure of the SNR for each line of the plots to the left: blue x's show the SNR measured for the positive arrival time, green x's show the measured SNR for the negative arrival time.***

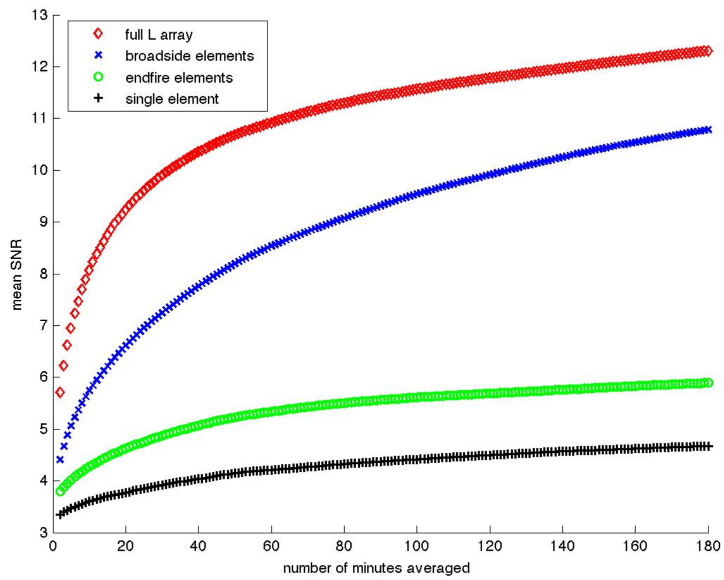


***Figure 3: Mean SNR buildup for the broadside to broadside arrays, endfire to endfire, and 'L' to 'L' shaped arrays. The horizontal axis shows the number of minutes averaged in one beam-to-beam correlation. Each value shown is the average SNR measured at all possible segments of that many minutes throughout the same four days of data. The red diamonds show the values from the full 'L' arrays, the blue x's are of beams made up of only the parallel portions of each array (i.e. the broadside beams), the green circles are of the in-line portion of the arrays (i.e. endfire beams), and the black + symbols are of a single sensor from each array.***

To complete this, we measure the noise energy from the two directions in line with the arrays (defined as 0° and 180°) and compare this with the results of the noise correlation of beams steered to either direction. When we take the difference between the noise measured to the two directions and compare it with the SNR measured (for 30 minute averages over the 4 days of the experiment) we see an agreement in sign of more than 73%. Figure 4 shows this comparison of the difference in the measured noise field vs the difference in the measured SNR – both plotted in dB.

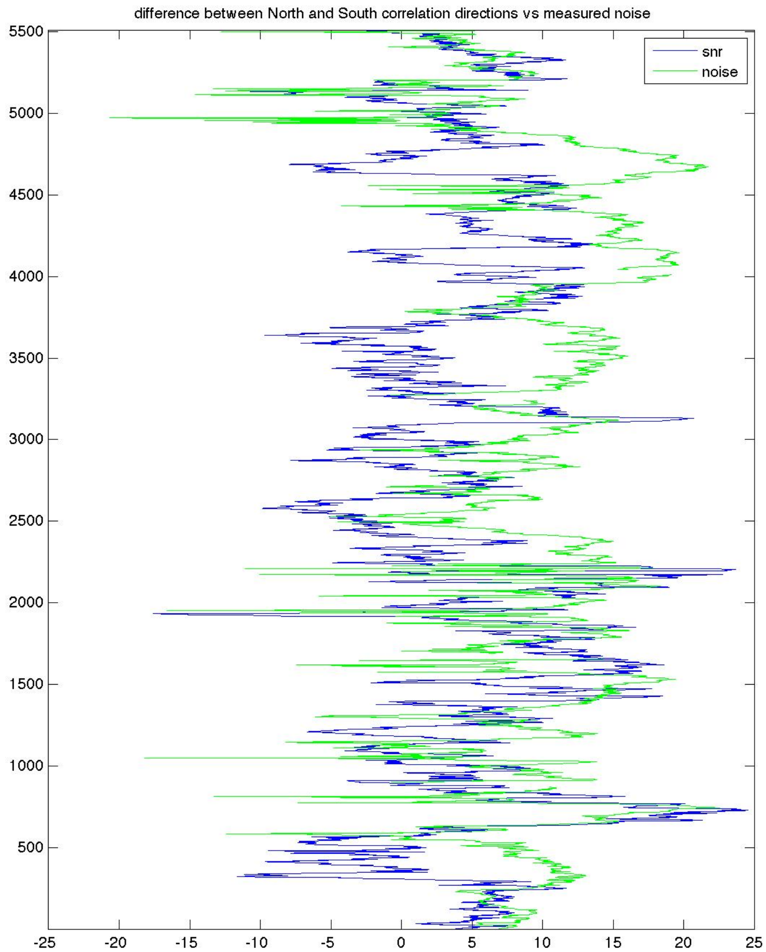


***Figure 4: Comparison of the difference between the measured noise field to 0° and 180° and the SNR measured from the correlation of noise from to 0° and 180°. The blue line is the difference in the SNR measurement in dB, the green line is the difference in the noise measurement. Greater noise from 180° gives positive measurements for both the noise and the resulting SNR of the correlation. The horizontal axis is the difference in dB, the vertical axis is the minute index of the experiment. Each measurement or correlation is of a 30 minute average of the noise.***

## IMPACT/APPLICATIONS

Potential future impact for Science and/or Systems Applications is that it finds application for noise, typically rejected and not further used.

## RELATED PROJECTS

This research is related to the ONR 6.1 program "Extracting Coherent Structures from High Frequency Ocean Noise."